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Scenarios in SYMOBIO 2.0

Ex-ante reference and bioeconomy wedges

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Disclaimer

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1 Introduction

In the Bioeconomy Monitoring Report 2024 (Beck-O'Brien et al. 2024) scenarios are developed and described in Section 7 to extrapolate the various footprints of the German bioeconomy into the future. In addition to a reference scenario, different wedges were developed, describing the effects of alternative future developments on the footprints. This discussion paper documents various assumptions behind these scenarios and presents selected results.

While EXIOBASE was used as the database for 49 regions in SYMOBIO 1.0, the MRIO calculations in SYMOBIO 2.0 are based on the GLORIA database. GLORIA (Global Resource Input-Output Assessment) is a multi-regional input-output database that was built by the University of Sydney using the IELab infrastructure for the UN International Resource Panel (UN IRP). GLORIA differentiates 164 regions and 120 sectors (see Table 20 and Table 21). The central multi-regional input-output tables includes supply-use transactions T, final demand y, value added v in 5 valuations (basic prices, trade margins, transport margins, taxes on products, subsidies on products) as a continuous time series for 1990-2027. Accompanying satellite accounts (extensions), cover GHG emissions, materials, energy, air pollution, land use, water use, biodiversity, skills and employment. Footprint trends have been calculated for all satellites from 1990-2027. The database is described in detail in Lenzen et al. (2017, 2022). For simulations in SYMOBIO we use data from GLORIA (Release 057) until 2021 as historical, because the data from 2022 onwards was only extrapolated using certain assumptions.

In the SYMOBIO 2.0 project, the model was used to quantify a reference scenario and various wedges The key assumptions for projecting the data set in ex-ante simulations into the future until 2050 are briefly described below. Differences in the results, including the footprints, can be attributed to the different assumptions in the reference scenario and in the wedges. The central model equations are described in Bringezu et al. (2021), and Helander et al. (2024). The bioeconomy wedges are simple "what-if scenario elements" to show alternatives to the reference development for specific aspects related to the bioeconomy. The wedge concept stems from Stefan Bringezu and Meghan Beck-O'Brien. Section 2.3.1 was written by Hanna Helander and Saskia Reuschel, section 2.3.2 by Karl-Friedrich Cyffka and Sören Richter, section 2.3.3 by Christian Lutz, section 2.3.4 by Christan Lutz and Saskia Reuschel, section 3.1 by Hanna Helander and Saskia Reuschel, section 3.2 by Sven Wydra, section 3.3. by Jan Schüngel and Rüdiger Schaldach, section 3.4. by Karl-Friedrich Cyffka and Sören Richter, and section 3.5 by Christian Lutz based on the concept from Anna Schomberg.

2 Reference scenario

2.1 General assumptions

General considerations on the scenario framework can be found in Lutz & Toebben (2023). The reference scenario describes largely continuity with regard to the influencing variables that are important for the development of the bioeconomy in Germany, Europe and the world. Important bioeconomy-specific targets are not achieved. In terms of framework data, the scenario is predominantly based on trends and expected developments. Only if significant deviations from trend developments are enshrined in law, as is the case with the energy transition in Germany and the EU with the Climate Protection Act and the Green Deal, or if there exist international projections for the case of global production of agricultural products or material extraction, is this taken into account in the reference.

In the reference scenario, it is assumed that economic growth in the individual countries develops in line with the SSP2 scenario according to OECD (Fricko et al. 2017, Dellink et al. 2017). For Germany only, reference is made to UBA (2022), which builds on long-term EU projections. Annual GDP growth rates for Germany will be below 1% until 2035, and around 1.4% p.a. afterwards. The structures in the individual countries in terms of intermediate and final demand and in global trade remain unchanged compared to 2021, apart from specific exceptions, which are described below. To project the country data with GDP growth, it is assumed that the domestic components of final demand, i.e. private and public consumption as well as investments, develop in line with the GDP growth rates. Population forecasts are also taken from the respective sources (Fricko et al. 2017, KC & Lutz 2017, UBA 2022).

Effects of increasingly frequent extreme weather events, droughts, and other climate change factors will affect the future of the bioeconomy but are not accounted for. Global geopolitical stability is also assumed in the modeling. Instability could have a significant impact on future developments, which is also not accounted for.

2.2 Energy transisiton and climate mitigation

In contrast to other areas of the economy, for which structural constancy is (largely) assumed until 2050, in the area of energy and climate protection Germany and the EU-27 as well as the other countries participating in the EU ETS will achieve their binding climate neutrality targets by 2045 and 2050 respectively. For the rest of the world the development is adjusted to the Stated Policies Scenario of the World Energy Outlook (IEA 2023). The modeling is important especially for the development of the bioeconomy's GHG footprint. It is based on experience gained from comprehensive climate mitigation modeling in Germany and the EU. It essentially transfers the foreseeable changes into the energy mix in the structure of the GLORIA MRIO data. Land-use change related emissions are not included. For further detail see section 7.6 of the Monitoring Report (Beck-O’Brien 2024).

For the energy transition in Germany, it is assumed that coal and petroleum products will no longer be used in electricity generation by 2038. Electricity generation from natural gas decreases by 50% between 2021 and 2040. As green hydrogen is not accounted for separately in the GLORIA product group classification, the corresponding power generation is mapped via the natural gas product group. In private households and in all product groups other than electricity generation, the energy transition will mean that fossil fuels can no longer be used by 2045. As with power generation, the use of natural gas (as a proxy for hydrogen) will remain limited. The use of electricity in private households and industry will increase significantly between 2021 and 2045 in order to compensate for the decline in fossil fuels. As a result, total energy expenditures will remain at about the same level as today. For the increased use of renewable energy sources, it is assumed that investments in equipment will be 10% higher annually than would be expected according to historical shares for 2021. For the countries participating in the EU ETS, i.e. the UK, Switzerland, Norway and Iceland in addition to the EU-27, comparable assumptions are made up to 2050, when the EU has to be climate-neutral in accordance with the Green Deal.

Table 1: Assumptions for energy use and climate mitigation

Product group	Sector (GLORIA classification)	Country/ region	Change compared to 2021
Fossil fuels without natural gas	Power generation (93)	Germany	Decrease to zero by 2038
Natural gas	Power generation (93)	Germany	Decrease to 50% by 2040
Renewables	Power generation (93)	Germany	Investments in machinery, equipment: +10% each year compared to reference
Fossil fuels without natural gas	Private households	Germany	Decrease to zero by 2050
Natural gas	Private households	Germany	Decrease to 50% by 2040
Electricity	Private households	Germany	Increase by 50% by 2045
Fossil fuels	All sectors except power generation and transformation (24-27, 62-63, 94)	Germany	Decrease to 10% by 2045
Electricity	All sectors except power generation and transformation	Germany	Increase in line with the decline in fossil inputs
Fossil fuels without natural gas	Power generation (93)	EU-Plus*	Decrease to zero by 2050
Natural gas	Power generation (93)	EU-Plus*	Decrease to 50% by 2040
Clean energy technologies	Power generation (93)	EU-Plus*	Investments in machinery, equipment: +10% each year compared to reference
Fossil fuels	Private households	EU-Plus*	Decrease to 10% by 2050

Electricity	Private households	EU-Plus*	Increase by 50% by 2050
Fossil fuels	All sectors except power generation and transformation (24-27, 62-63, 94)	EU-Plus*	Decrease to 10% by 2050
Electricity	All sectors except power generation and transformation	EU-Plus*	Increase in line with the decline in fossil inputs
GHG emissions	All sectors	EU Plus	CO_2 intensity decreases 5% p.a. to meet EU reduction targets in 2050; CH_4 and N_2O intensity decrease by 2% p.a.
GHG emissions	All sectors	World without EU Plus	CO_2 intensity decreases 4% p.a. to meet IEA stated policies scenario in 2050; CH_4 and N_2O intensity decrease by 3% p.a.

Source: Own compilation; *EU-Plus without Germany

Nevertheless, decarbonization cannot be fully reflected in the GLORIA dataset because key new technologies as PV, hydrogen or e-fuels are not directly mapped. Assumptions on GHG intensity have therefore also been made for European countries so that the results of the Green Deal are ultimately achieved for the EU including those countries that participate in the EU ETS as the UK, Switzerland and Norway (EU Plus). For the countries outside the EU Plus, comparably simple assumptions are made so that global GHG emissions in 2050 roughly correspond to the Stated Policy Scenario of the World Energy Outlook (IEA 2023), which is not in line the targets of the Paris agreement to limit global temperature growth below 1.5° or least 2°.

2.3 Bioeconomy (Reference)

2.3.1 Diets

The assumptions on diets in the reference are based on the trends in food consumption in Germany for the years 2010 to 2021, originating from the Statistical Yearbook of BMEL (2022) Chapter D ("Verbrauch von Nahrungsmitteln je Kopf"). Table 2 shows food consumption in kg per capita in Germany for the years 2010 and 2021, the identified trend over this period and the derived values for 2030 (see also Table 22 for more detail). The findings in the last two columns are the result of our own time series regression analyses based on the BMEL data. During the considered period from 2010 to 2021, the consumption of meat and meat products decreased significantly, while the consumption of rice increased. For all other crops and food, no significant trend could be detected.

Table 2: Food consumption in kg per capita in Germany

	2010	… [1]	2021	Trend [2]	2030 [2]
Cereal products (flour value)	93.4	…	84.6	no trend	84.6
Rice	5.0	…	6.6	+0,11 kg/year	7.6
Potatoes	64.5	…	59.6	no trend	59.6
Vegetables, fruit (market cultivation)	224.1	…	222.7	no trend	222.7
Sugar including beet juice (white sugar)	34.6	…	32.5	no trend	32.5
Meat and meat products (slaughter weight)	91.2	…	82.1	-0,38 kg/year	78.6
Fish and fish products (catch weight)	16.0	…	12.7	no trend	12.7
Milk and milk products	115.4	…	115.9	no trend	115.9

Source: BMEL (2022)

[1] The values for the years 2011 to 2020 are not listed here but can be found in the appendix.

[2] The findings in the last two columns are the result of our own time series analyses based on the BMEL data for the years 2010 to 2021

For future private demand for food in Germany, we assume an annual decline of 0.48% for meat and an annual increase of 1.57% for rice in line with Table 3. Demand for all other food products will remain constant in absolute terms in the future as we assume constant demand for other food in kg. For the ex-ante calculations, we set the monetary demand according to the assumed future development of the diets in kg.

Table 3: Assumptions for German diets in the reference

Product group	Sector	Country	Change compared to 2021
Meat	Private consumption	Germany	Annual decrease by 0.48% acc. to historic trend
Rice	Private consumption	Germany	Annual increase by 1.57% acc. to historic trend
All other food	Private consumption	Germany	No change in weight units

Source: Own compilation

2.3.2 Bioenergy and biomaterials

The first step of development of the reference scenario includes the assessment of relevant policy and political target settings. The assumptions made for the reference case of bioenergy are based on the current regulatory framework for Germany, while the assumptions for the reference case of biomaterials are based on objectives of the EU Commission within the Green Deal. As a second step, the current usage levels of biomass (focus on crops) were analysed with regard to the possible future usage developments. In a third step, GWS converted this information into the GLORIA classifications for biomass. The focus of the scenarios for biomass demand lies mainly on biomass that is cultivated on agricultural areas (crops) for further usage, because assessments of the associated agricultural land demand can be derived in the subsequent analysis.

Within the **transport sector**, the central regulatory instrument is the EU Renewable Energy Directive (REDII, 2018) and its revision in 2023 (REDIII) (Council of the European Union; European Parliament 2018, 2023). The aim of the directive is to reach a minimum share of alternative and renewable energy carriers in the transport sector (REDII: 14 % until 2030). Further, the directive includes minimum contributions for sustainability requirements and minimum targets for greenhouse gas emission reductions of energy carriers (Naumann et al. 2021). For the implementation of the EU directive in Germany the Greenhouse gas quota is implemented (§37 a-d Federal Immission Control Act - BImSchG) (Deutsche Bundesregierung 2024). The principle is that distributors of fuels have the obligation to report the distributed fuels and to reduce continuously their GHG emissions by blending fossil fuels with renewable fuels. While the focus of the narrative development is on agricultural biomass and especially crops, it is necessary to consider the 38th Federal Emission Protection Order (§13 38. BImSchV), which entails a maximum quota for fuels based on food and feed crops from 2022 onwards of a maximum of 4.4 % of the final energy in transport (Deutsche Bundesregierung 2023).

In order to acquire insights about the impact of biomass use in the sector, assumptions for the final energy demand are developed. These are based on developed and modelled scenario assumptions of climate neutrality scenarios for Germany (Stiftung Klimaneutralität et al. 2022). For the maximum value of final energy demand development until 2050 the scenario BMWK – LFS TN-Strom is used, and for the minimum value of final energy demand development until 2050 the Dena- KN100 is used (Sensfuß et al. 2021; Deutsche Energie-Agentur 2021). The elaborated final energy assumptions for the transport sector are based on these scenario bandwidths.

Table 4: Final energy demand in transport for narrative development in SYMOBIO

Scenario/Assumptions name	Reference (2018)	2030	2040	2050
BMWK LFS TN-Strom TWh/a	721	654	488	375
BMWK LFS TN-Strom PJ	2,596	2,354	1,757	1,350
Dena- KN100 TWh /a	647	426	255	215
Dena- KN100 PJ	2,329	1,534	918	774
End energy demand assumption SYMOBIO TWh /a*	684	540	372	295
End energy demand assumption SYMOBIO PJ*	2,462	1,944	1,337	1,062

*own calculation: Value Dena- KN100 + ((Value BMWK LFS TN-Strom – Value Dena- KN100)/2)

Based on the assumptions made (Table 4) the following factors are relevant for the reference case:

- Reduced cultivated biomass usage in the transport sector due to reduced final energy demand in the sector.
- The GHG-Quota as most important regulatory framework is assumed to be continued on the same level for food and feed crops (4.4 % of final energy demand) until 2050.
- Focus is on the used biofuels in Germany (Bundesanstalt für Landwirtschaft und Ernährung 2022a).
- Advanced biofuels included for maritime and ships based on lignocellulosic materials (non-food crops from degraded lands) from 2040 on.

Table 5: Narrative development for the biofuel usage in transport in SYMOBIO with the reduction (in %) of final energy demand

Unit	2020*	2021**	2030***	2040***	2050***
Final energy demand assumption SYMOBIO in PJ*	2,283	2,253	1,944	1,337	1,062
Biogenic renewable raw materials used for biofuel production (waste and residues excluded) in PJ	122	99	88	56	48
% of biofuels generated by cultivated renewable raw materials in relation to end energy demand	5.2 %	4.4 %	4.4 %	4.4 %	4.4 %
Reduction in % biofuel production from cultivated renewable raw materials (reference 2020)		-19 %	- 30 %	- 52 %	- 62 %

* (Bundesanstalt für Landwirtschaft und Ernährung 2022b; Schröder and Naumann 2022); ** (Bundesministerium für Digitales und Verkehr/Federal Ministry for digital and transport 2022; Bundesanstalt für Landwirtschaft und Ernährung 2022b); ***own calculation: Value Dena- KN100 + ((Value BMWK LFS TN-Strom – Value Dena- KN100)/2)

The reference case results indicate that the energy use of crops for conventional biofuels in transport will decline significantly in Germany. Compared to 2020, the biofuel quantities used in transport will fall by 30 % by 2030, by 52 % by 2040 and by 62 % by 2050, which is due to future decreases in final energy demand of the transport sector in combination with the respective maximum quota for conventional biofuels (food/feed). Biofuels obtained from palm oil will no longer be used from 2024 (modelled as a 25 % reduction in oil seed imports from Indonesia and Malaysia). Future reductions of palm oil are compensated by other crops with regard to their shares as well as origin in 2020. In 2030, almost three quarters of the biomass source materials will come from Germany or the rest of Europe. In addition, rapeseed from Australia and North America as well as soy and sugar cane from Latin America will be used. In addition to altering input biomass for conventional biofuels, additional data are included in the biofuel sector to integrate future expectations on further fuel categories and in which sectors these are used. From 2040, advanced biofuels from perennial/woody crops originating from Europe will also be used. They are accounted for as fiber crop inputs to substitute conventional petroleum products.

Table 6: Assumptions on crop based biofuel use in Germany in the reference case in t of renewable raw materials

Fuel categories	2020	2030	2040	2050
Conventional biofuels	15,016,466	7,747,603	5,312,642	4,205,842
Perennial/woody crops (SRC) – advanced biofuel			3,700,000	7,400,000
Biofuels in transport	15,016,466	7,747,603	9,012,642	11,605,842
Liquid biofuels (electricity and heat)	517,239			

Source: Own calculation based on BLE (2024) for 2020 and assumptions made before in Table 5 for future developments of conventional biofuels. Conversion factors (ton of crop/t of biofuel) based on (DBFZ 2016, DBFZ 2015a and DBFZ 2015b). Assumptions for perennial/woody crops (SRC) – advanced biofuel: overall EU demand ~ 15 Mtoe for short rotation coppice in 2050 (628 PJ) ~ 37 Mio. t (heating value 17 GJ/t) following (European Commission 2020); Share Germany: 7,4 Mio. t in 2050 (2040: 50 %) according to German energy demand share in transport of ~ 20 % in EU. Wood from forests excluded in this analysis.

Table 6 illustrates that from 2040 advanced biofuels from perennial and woody crops originating from Europe will also be used. This is in line with the EU modeling results of the impact assessments of the REDIII (European Commission 2020). Required feedstock amounts of short rotation coppice are allocated for Germany considering the German energy demand share of the transport sector within the EU. Due to already low usage levels and a substantial decrease from 2020-2022, liquid biofuels for electricity and heat production are assumed to be no longer needed in 2030 (Bundesanstalt für Landwirtschaft und Ernährung 2024).

In the reference case for the **electricity and heat sector** (focus on biogas plants) the most important regulatory framework is the renewable energy law. Within the EEG 2023, the tender volume for biogas is reduced as follows, 600 MW in 2023, 500 MW in 2024, 400 MW in 2025 and in the years 2026 until 2028 with a steady amount of 300 MW. For biomethane plants the tender volume is from 2023 until 2028 at 600 MW (Deutscher Bundestag 2024). The assumptions used in the reference case for the development of biogas and biomethane production is based on the latest DBFZ Report Nr. 50 (Rensberg et al 2023). In the realistic scenario difficult market circumstances for biogas production as well as the regulatory obstacles have led to undersigned tenure tracks for biomass. In this scenario conservative assumptions have been made for biogas plants that use renewable raw materials, solid biomass and waste. In this narrative, a minority of plants make use of opportunities to extend the operation of their plants which led to a reduction of installed capacity of operation plants. The decrease leads to a reduction of biomass usage from cultivated areas for this energy application. Table 7 illustrates the development of installed capacity in MW of the years 2020-2030.

The following main assumptions are relevant for the reference case (Table 8):

- In reference case the use of biomass to generate electricity and heat will decrease by 25 % from 2020 to 2030 due to regulatory management of tenure tracks.
- Thereafter, the quantities remain unchanged until 2050.

Table 7: Installed capacity of biogas in electricity and heat in MW based on DBFZ Report Nr. 50

Capacity development for specific operations	2020	2021	2022	2023	2024	2025	2030
Slurry BGP*	71	72	72	74	76	80	88
Waste-BGP*	138	138	134	139	139	140	140
Renewable raw materials-BGP*	5,637	5,641	5,637	6,099	6,082	6,075	4,090
Biomethane	530	530	529	529	529	528	467
hf**-Biomethane	0	0	3	3	28	34	54
Sum of plants that use renewable raw materials	6,167	6,171	6,169	6,631	6,639	6,637	4,611
Reduction of cultivated biomasses for biogas production in comparison to 2020 in %		0 %	0 %	+8 %	+8 %	+8 %	-25 %

Source: own calculation based on assumptions made in Rensberg et al. (2023); *BGP = biogas plant; ** hf = highly flexible

Table 8: Assumptions on the use of biomass from fermentation in electricity and heat generation in Germany in the reference in t of renewable raw materials

QUANTITY OF USE (in tons)				BAU
Use	**Bioenergy carrier**	**Raw material**	**2020**	**2030**
Electricity and heat*	**Biomethane (incl. biomethane for fuel use*)**	Maize silage	43,500,000	32,625,000
		Grass silage (incl. GPS from legumes / catch crops / other renewable raw materials)	10,740,000	8,055,000
		GPS (cereals)	4,970,000	3,727,500
		Cereal grain	1,860,000	1,395,000
		Sugar beet	1,940,000	1,455,000

Source: own calculation based on data of FNR (2024) and Rensberg et al. (2023); *marginal share of biomethane from crops for fuel use according to BLE (2024)

Agricultural cultivated biomass is used in the material sector primarily in the **chemical sector**. In the reference case the quota proposal of the EU Commission is used. The “Sustainable Carbon Cycle” communication of the EU Commission entails the aim of 20 % of renewable carbons based on non-fossil raw materials for 2030 (European Commission 2021). This regulatory framework indicates that biomass will have a part in the future raw material mix of the chemical sector, which also confirmed by the meta-analytical comparison of scenario studies in the respective sector (Kloo et al. 2023). Following these results, another limited increase for the year 2050 with a share of 30 % of renewable raw materials usage is assumed. Based on these assumptions in combination with integration of prospective demands that will take place in the year 2024, following results are used for the reference case.

Table 9: Assumptions for biomass usage in the chemical sector in the reference narrative

Categories for calculation	2020*	2025	2030	2050
Production capacity (in Mio. t)	19.9	19.9	19.9	19.9
Share (%) of biogenic input material at the production capacity	12.4 %	14.87 %	20 %	30 %
Usage of biogenic input materials in the sector (in Mio. t)	**2.46**	**2.96**	**3.98**	**5.97**
Assumed amount of cultivated renewable raw materials (in Mio. t)*	2.46	2.46	2.46	2.46
Assumed amount of lignocellulosic raw materials (in Mio. t)**		0.5	1.52	3.51
Lignocellulosic materials from primary sources, forest (in Mio. t)***		0.5	1.44	2.46
Lignocellulosic materials from primary sources, agricultural areas (in Mio. t)***			0.08	1.05
Lignocellulosic materials from primary sources, agricultural areas (in ha)****			7,600	105,300
Sum of biomass on areas outside of forests (agricultural biomass) (in Mio. t)	2.46	2.46	2.54	3.51*****

Sources: * (Becker et al. 2023) ** including case of (Biorefinery Leuna | UPM Biochemicals 2023); *** 2030: 95 % forest (Öko-Institut e.V. 2021); 5 % lignocellulosic from agricultural areas; 2050: 70 % forest; 30 % agricultural areas; ****assumption 10t/ha (Fehrenbach et al. 2017) *****following (Benndorf et al. 2014)

This leads in the reference case for agricultural biomass in the chemical and other industrial sectors to an increase by 3 % by 2030, 20 % by 2040 and 43 % by 2050 compared to 2020. Table 10 summarizes all the above outlined assumptions for biomass use according to the product and sector groups within the GLORIA modelling.

Table 10: Assumptions for biomass use in the reference scenario

Product group	Sector	Country	Change compared to 2020
Maize, cereals, oil seeds, sugar	Power generation (93)	Germany	Decrease by 25 % by 2030
Maize, cereals, oil seeds, sugar	Refined petro products (63)	Germany	Decrease by 30 % by 2030, 52 % by 2040, 62 % by 2050

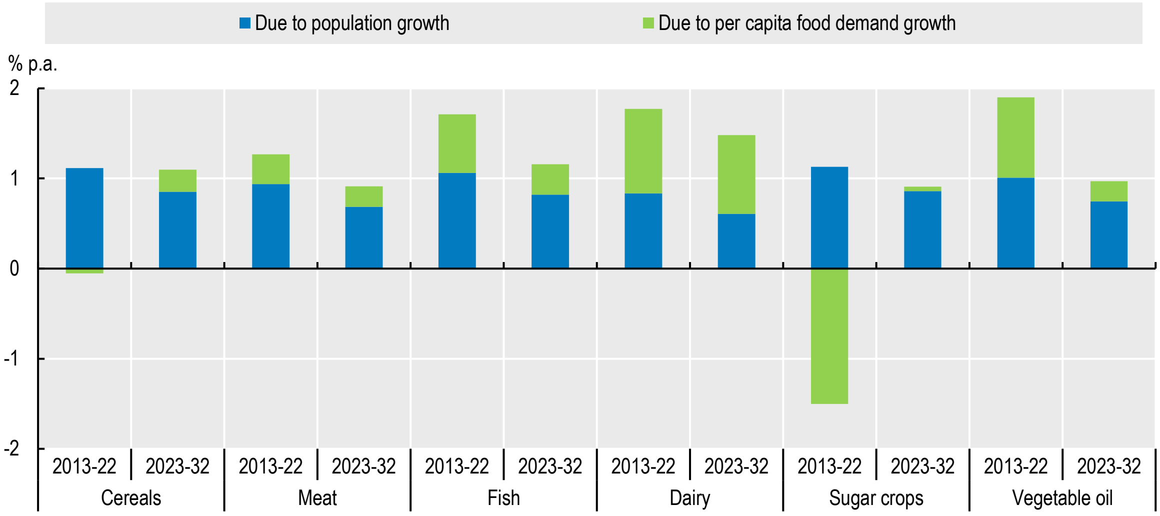
Organic chemicals,	Refined petro products (63)	Germany	Decrease by 30 % by 2030, 52 % by 2040, 62 % by 2050
Vegetable oil	Refined petro products (63)	Germany	Decrease by 30 % by 2030, 52 % by 2040, 62 % by 2050
Fibre crops	Refined petro products (63)	Germany	Increase to 1 % of output by 2040, 2 % by 2050
Oil seeds (4)*	Shares of Indonesia, Malaysia in German imports	Germany	Decrease by 50 % in 2024
2, 4, 6, 10, 21, 51-53	Basic organic chemicals (68), Dyes, paints, glues, detergents and other chemical products (70)	Germany	Increase of 3 % by 2030, 20 % by 2040, 43 % by 2050
Forestry and logging (21) **	Rubber products (71)	Germany	Increase of 3 % by 2030, 20 % by 2040, 43 % by 2050
Sugar refining (51), Basic organic chemicals (68)	Clay building materials (73)	Germany	Increase of 3 % by 2030, 20 % by 2040, 43 % by 2050
Maize (2), vegetables, roots, tubers (6)	Pulp and paper (60)	Germany	Increase of 3 % by 2030, 20 % by 2040, 43 % by 2050
Maize (2), vegetables, roots, tubers (6)	Basic organic chemicals (68)	Germany	Increase of 3 % by 2030, 20 % by 2040, 43 % by 2050

Source: own calculation based on table from DBFZ. * Excluding palm oil, which is reduced by 100% until 2024. ** The GLORIA sector classification is not entirely clear in this case. Wood from forestry (except rubber) is not included here.

2.3.3 Global development of agricultural goods production

FAO (2023) projections up to 2032 are available for the global production of agricultural goods by key commodity groups. According to these projections, total demand for meat, fish, dairy products and, above all, vegetable oil will weaken over the next 10 years compared to the corresponding period in the past from 2013 to 2022. In contrast, the average annual growth in cereals will remain largely unchanged compared to past trends. Sugar production will even increase significantly. For the product groups listed below, these expected annual growth rates for cereals, meat, sugar plants and vegetable oil are in the order of 1%, for fish they are slightly higher at 1.15% and for dairy products they are significantly higher at 1.48%. Between 2013 and 2022, global sugar crop demand was reduced, as reductions due to food demand change outweighed population growth.

Figure 1: Average annual growth in demand for key commodity groups, 2013-22 and 2023-32



Source: OECD/FAO (2023), "OECD-FAO Agricultural Outlook", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/agr-outl-data-en.

In principle, it can be assumed that global demand for the relevant commodity groups will develop at a similar rate in the future. Precise calibration to these developments is not easy to implement in the GLORIA dataset, but reached closely, according to Table 11. For the calculations of future footprints, changes in monetary demand are interpreted as changes in physical demand.

Table 11: Assumptions for global agricultural production

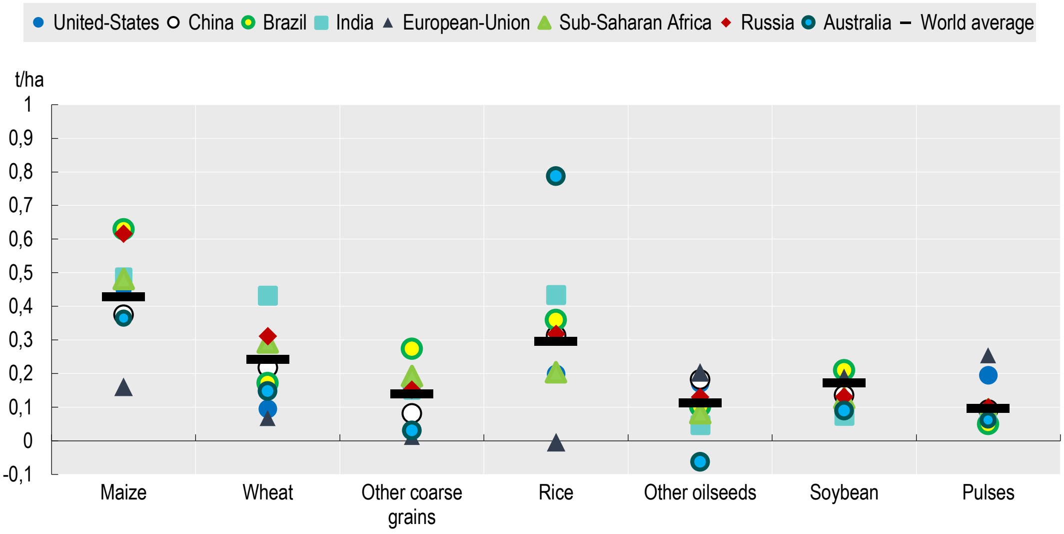
Product groups according to FAO (2023)	Product groups in GLORIA	Country	Annual change according to FAO in % (2022-2032)	Annual change in global production in MUSD in the reference (2024 to 2030)
Cereals	1, 2, 3, 5, 47	all	1.09	1.0 to 1.2
Meat	16-20, 41-45	all	0.92	0.8 to 1.1
Fish	22, 23, 46	all	1.15	1.0 to 1.3
Dairy products	54	all	1.48	1.2 to 1.5
Sugar crops	7	all	0.91	0.8 to 1.0
Vegetable oil	53	all	0.97	0.5 to 1.0

Source: OECD/FAO (2023), own calculations based on GLORIA

No difference is made between developed and developing countries beyond the different GDP growth rates. This approach differs from SYMOBIO 1 (Bringezu et al. 2021). For the pilot monitoring report (Bringezu et al. 2021) projections of per-capita crop and per-capita livestock demand in other countries and world regions were used from the SSP2 quantification of the Integrated Assessment Model MESSAGE-GLOBIOM from the International Institute for Applied Systems Analysis (Riahi et al. 2017).

Yields per hectare develop according to the OECD/FAO (2023) outlook. This includes the developments for important countries and country groups as well as crops according to Figure 2. For the other countries and product groups, reference is made to global trends in the outlook. After 2032, the changes of the period from 2022 to 2032 are extrapolated.

Figure 2: Assumptions for change in projected yields for selected crops and countries between 2022 and 2032

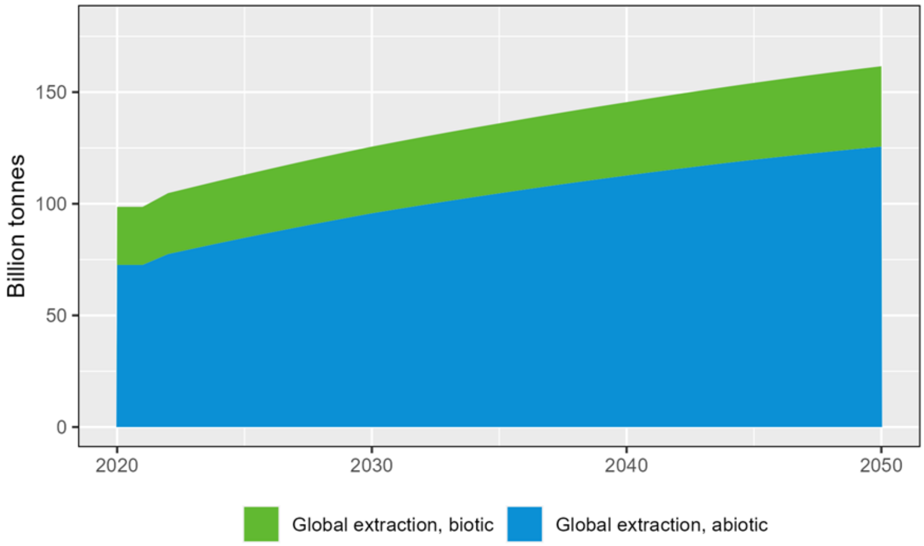


Source: OECD/FAO (2023), "OECD-FAO Agricultural Outlook", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/agr-outl-data-en.

2.3.4 Global development of resource extraction

The long-term development of global extraction for key biotic and abiotic raw materials up to 2050 is calibrated to the historical trend scenario of the global resource outlook (UNEP 2024, p. 83). In the scenario, global resource consumption rises sharply until 2050 before stabilizing, from about 100 billion tonnes in 2020 to around 160 billion tonnes in 2050. The development is largely driven by upper middle-income economies moving from a resource-intensive growth phase into more value-added activity (UNEP 2024). Figure 3 shows the similar global extractions in the SYMOBIO Reference scenario.

Figure 3: Reference: Global domestic extraction in billion tonnes

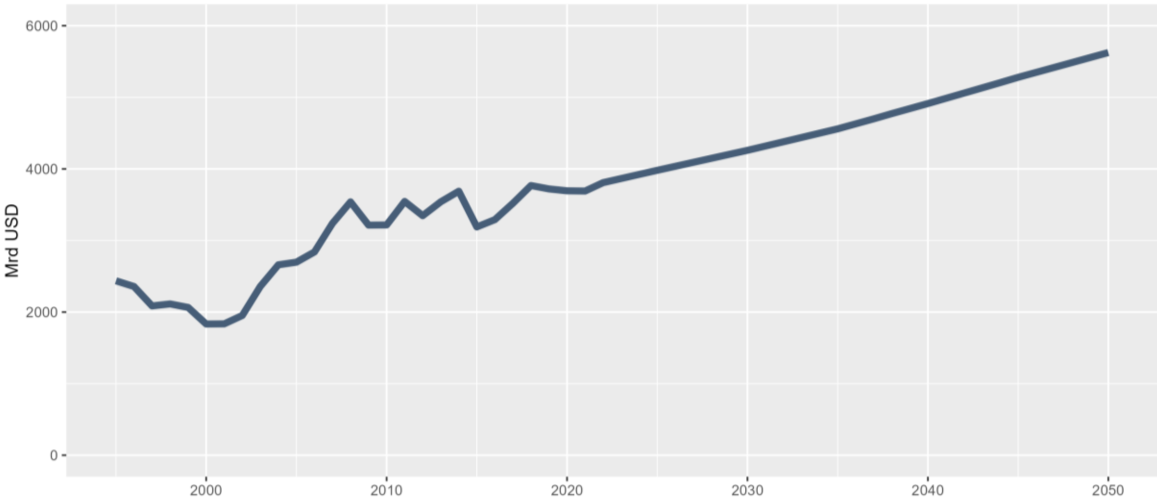


Source: GWS based on GLORIA

2.4 Central results: Reference

According to the assumptions in section 2.1, GDP in Germany will develop in line with the long-term development in UBA (2022) (see Figure 4). Especially GDP growth after 2035 is higher in this publication than in other projections. Assumptions of weaker future economic growth would, ceteris paribus, also reduce the footprint. However, assumptions about the development of food demand and energy use are already specified separately, so the influence of GDP on the variables is likely to be limited.

Figure 4: GDP in Germany in the reference in billion USD



Source: UBA (2022), GWS, own conversion into USD with exchange rates of 2021.

For the use of biotic resources, we show **domestic extraction** (DE, e.g. wheat production), **raw material consumption** (RMC = DE + IM - EX), as the sum of imported (IM) and domestic extraction in raw material equivalents (RME) for domestic final demand minus exports (EX), and **raw material input** (RMI = DE + IM), which also takes raw material extraction for exports in raw material equivalents (EX) into account in addition to domestic final demand (see Eurostat 2024).

The results for the agricultural biomass and for the climate footprint are put into context and shown below as examples. Detailed results also for other footprints can be found in the monitoring report (O'Brian et al. 2024). German domestic extraction of crops and plant residues, fodder crops and grazed biomass will decrease slightly in the long term. The development of the agricultural biomass footprint shows the consequences of the pandemic in the GLORIA data, which led to a significant decline in economic activity and international trade in 2020 and 2021. Accordingly, agricultural biomass raw material consumption (RMC) and raw material input (RMI) are also lower in 2022 than in the years prior to 2020.

The agricultural biomass footprint (RMC) has already developed slightly downwards until 2021. It will continue to decline slowly after 2022. It is around 80% higher than domestic extraction, which means that German final demand is highly dependent on imports. For this reason, a global view is important. The agricultural biomass raw material input (RMI) is even higher. It also includes material extraction for German exports in addition to the RMC. The German biotic RMI will decline slowly from around 600 million tons in 2022 to 2050.

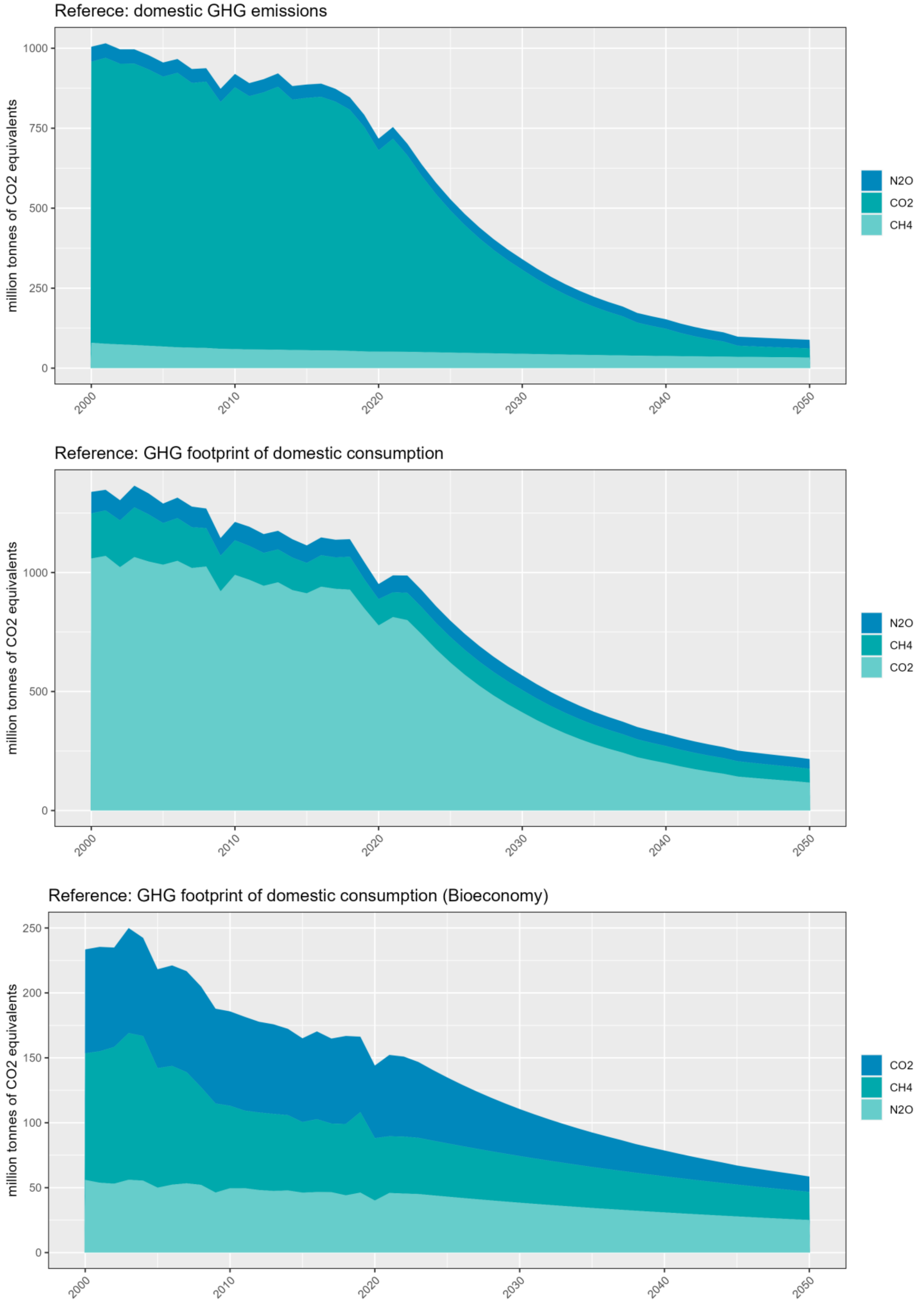
Some of the footprint results for the historical period show developments in the years from 2017 onwards that cannot be explained by the development of the national extraction data in the GLORIA satellite balances. Here, analyses of the monetary input structures show some leaps and breaks that have resulted from the underlying OECD input-output tables. With the next update, the FPs will be recalculated.

When interpreting the following indicators, it should be noted that, apart from the changes at product group level described above, structural constancy is assumed in the reference for the future. This means that demand for all product groups not explicitly treated differently grows with GDP. Structural change away from agriculture and forestry and towards services beyond the assumptions described above would tend to lead to lower values for biotic RMC and RMI in the future.

Figure 5: German agricultural biomass domestic extraction, RMC and RMI in the reference

Source: GWS, own calculation based on GLORIA.

Figure 6: Domestic GHG emissions, GHG footprint of domestic consumption (total and bioeconomy)



Source: GWS, own calculation based on GLORIA.

The MRIO model can also be used to determine the GHG emissions of the individual countries and the GHG emissions attributable to domestic final demand based on the GLORIA data, which are also referred to as the climate footprint. The emissions data in GLORIA comes from the EU's global EDGAR database (https://edgar.jrc.ec.europa.eu/). They do not correspond exactly to the GHG emissions reported by the UBA for Germany. A big advantage of EDGAR is the uniform and detailed global coverage.

Figure 6 above first shows the German GHG emissions according to the standard international production approach. This includes the emissions released during production and consumption activities on German territory. In contrast, the climate footprint takes into account the global emissions caused by the production and transportation of goods that are finally consumed in Germany. The last figure shows the climate footprint of the German bioeconomy. It includes the global emissions for final demand of bioeconomy goods in Germany. It is important to note that the reference assumes that Germany will achieve its climate targets by 2045. It is also assumed that the EU will be climate neutral by 2050. A comparison of the figures shows that methane and nitrous oxide emissions play a much greater role for the bioeconomy than for the economy as a whole. This could also increase the pressure on agriculture and forestry to reduce their GHG emissions even more in the long term.

3 Bioeconomy scenarios – Wedge approach

The wedges considered in the following are simple "what-if scenario elements" to show alternatives to the reference development. They explore "options" for alternatives by isolating parameters that could contribute to (or harm) a sustainable transition. The wedges show the relevance for policy in relation to the key levers of change.

In each case, individual parameters in the GLORIA-based MRIO model are adjusted in a comparative-static analysis, each of which is described below. There are no market reactions considered. This means, for example, that a decline in meat consumption in Germany does not lead to changes in demand (via changes in world market prices in other countries). If direct adjustments are assumed, such as an increase in demand for other food in the event of a fall in meat consumption, they are incorporated directly into the model and described below.

The focus of this report is on agricultural biomass, but similar issues should also be modelled for forestry in the future. The individual wedges can be combined into transformation scenarios. The report also serves to highlight modelling capacities and types of questions that can/should be explored for bioeconomy monitoring.

3.1 Dietary change

Dietary changes and in particular the decrease of animal products in German average diets have high potential to decrease the pressure on agricultural land and thereby also decrease carbon emissions and water use. A decrease in raising cattle also directly decreases methane emissions (see Deliverable 1.3.1). For health reasons, dietary recommendations also suggest a decrease in meat and partly in milk in Germany (Schäfer et al. 2024, Oberritter et al. 2013; Willett et al. 2019).

The wedge of changed dietary patterns includes reduced meat consumption, and reduced milk consumption. The reduction rates are based on the food-based dietary guidelines (FBDG) updated by the Deutsche Gesellschaft für Ernährung e. V. (DGE) in 2024 (Schäfer et al. 2024). For the revision of the FBDG, the DGE has developed a new methodology based on mathematical optimization, which simultaneously considers health aspects, environmental aspects (greenhouse gas emissions and land use) and the usual consumption patterns in Germany. The deviation from the usual consumption is thereby kept as low as possible (Schäfer et al. 2024). Compared to the previous recommendations (Oberritter et al. 2013), the proportion of animal-based food is lower. The revised recommendations include two portions of milk and dairy products a day (one portion less than before) and it is stated that it is sufficient to eat a maximum of 300 g of meat per week (DGE 2024). To determine current intake, we use data on food consumption and intake from the BMEL Statistical Yearbook (BMEL 2023a, b).

For meat products we use data on meat intake ("Verzehr") from BMEL (2022). We do not use the data from the National Food Consumption Survey II (NVS II), firstly as these are relatively old (survey period 2006) and secondly because a recent study by Max Rubner Institute and Thünen (Thiess et al. 2022) tends to confirm the level of the BMEL meat intake data. As BMEL (2022) does not provide data on intake for milk products as they do for meat products, we use the data on milk consumption ("Nahrungsmittelverbrauch") and adjust for household food waste, which is estimated to 14% for milk products according to WWF (2015). FAO conversion factors (FAO 1972) are used to convert to milk equivalents.

Table 12: Comparison of current intake, DGE and EAT Lancet recommendations.

GLORIA Sectors		Current Intake (BMEL) 2022 (g/day)	DGE 2024 rec. (Schäfer et al. 2024)	DGE rec. old (Oberritter et al. 2013)	EAT Lancet rec. (g/day)	
41	Beef meat	26	26-43	43-86	7	(0-14)
42	Sheep meat	2				
43	Pork	78			7	(0-14)
44	Poultry meat	34			29	(0-86)
45	Other meat products	3			-	
	SUM Meat products	143	26-43	43-86	43	(0-86)
54	Dairy products [1)]	706	500	700-850	250	(0-500)

[1)] Raw milk equivalents. Current intake is converted using extraction rates from FAO (1972).
Intake is estimated to be 14% lower than consumption, due to food waste in households (WWF 2015)

Note : The DGE recommendations are not specific to different types of meat but refer to total meat consumption.
Sources: Current intake: BMEL (2023a, 2023b), DGE 2024 rec: Schäfer et al. (2024), DGE rec: Oberritter et al. (2013), EAT Lancet rec: Willett et al. (2019)

Table 12 shows the comparison of current intake, the revised and previous DGE recommendations and the EAT Lancet recommendations. The EAT Lancet recommendations (Willett et al. 2019) are developed to support globally both human and planetary health. A DGE statement compares the recommended food quantities of the Planetary Health Diet with the (previous) food-based dietary guidelines of the DGE (Oberritter et al. 2013) and with data on actual food intakes in Germany and contextualizes the significance of the Planetary Health Diet for Germany accordingly (Breidenassel et al. 2022).

For the Dietary Change Wedge, the mean values of the DGE recommendation are used and compared with the current intake. Table 13 shows the factoral change and the percentage decrease to reach the DGE recommendations compared to the current intake. The meat products are grouped and a reduction of 76 % is needed, and the milk reduction corresponds to 29 %.

Table 13: Wedge Dietary Change (DGE)

GLORIA Sectors		Current Intake (BMEL) (g/day)	DGE rec. 2024		decrease %
		2022	mean	(range)	
41-45	All Meat products	143	34	(26-43)	**76%**
54	Dairy products [1)]	706	500	(500)	**29%**

Notes:[1)] Raw milk equivalents. Current intake is converted using extraction rates from FAO (1972). Intake is estimated to be 14% lower than consumption, due to food waste in households (WWF 2015)

Sources: Current intake: BMEL (2023a, 2023b), DGE rec: Schäfer et al. (2024).

For the Wedge Dietary Change (DGE), it is assumed that the DGE recommendations will be achieved in Germany in 2050 and that the decline in this period will be linear. The decline in consumption is modelled as a decline in consumption expenditures as shown in Table 14.

Table 14: Assumptions for the wedge Dietary Change (DGE)

Product group	Sector	Country	Change compared to 2021
Meat	Private consumption	Germany	Decrease to 24% by 2050
Dairy products	Private consumption	Germany	Decrease to 71% by 2050
Meat	Food products	Germany	Decrease to 24% by 2050
Dairy products	Food products	Germany	Decrease to 71% by 2050

Source: Own compilation based on BMEL (2023a, 2023b), Schäfer et al. (2024).

In addition, it would be possible to vary the DGE assumptions in sensitivity calculations or to include other assumptions on dietary patterns in the model, such as those from EAT Lancet.

3.2 Alternative meat

In the recent past, different meat alternatives have been developed to replace additional meat. Most important are plant-based meat alternatives (PBMA), which are based on plant proteins, isolated from agriculturally grown crop plants such as wheat, soybeans, peas, and beans etc. In addition, a potential solution is cultivated meat[1] that is produced by cultivating animal cell lines in bioreactors under controlled conditions. The substitution of meat by alternatives is expected to have significant structural impact as livestock farming would significantly change towards either more plant farming or industrial production in case of cultured meat. However, projections on value chains and market volumes are highly uncertain, as they depend largely on presumed technological progress, in particular for cultivated meat, as well as consumer behaviour and market regulation.

In order to estimate the potential range of impacts, we assume a scenario of a significant uptake of alternative meat, including a successful market entry of cultivated meat. We take estimates in the middle range of existing studies, which still would indicate a very significant take up of alternative meats. Therefore, we take the moderate scenarios on market projections and considerations of an OECD scenario (OECD 2022) and assume a decrease of meat consumption about 10% for 2030, which is substituted by plant-based meat (90%), but also to some extent by cultivated meat (10%). From 2040 on, a market share of 25% of alternative meat, with 60% presented by plant-based meat and 40 % cultivated meat is assumed, which is in between of the bandwidth of estimations. It is assumed that the projected decrease of meat productions takes place proportionally for beef, pork, poultry and other meat products.

With the underlying assumption of price parity of meat and substitutes – which is very congruent/plausible in such scenario of significant diffusion - cost structures are of significant importance to model the value chains in input-output based model. There have been a number of recent studies that perform techno-economic analysis in the case of cultured meat (Pathirana 2024; Sinke et al. 2023; Specht 2020; CE Delft 2021). Unsurprisingly the studies differ significantly in cost estimates, and these depend highly on the advances and efficiency of large-scale recombinant protein production. As for broad diffusion, a high-cost competitiveness of cultivated meat has to be reached; optimistic estimations are taken for deducing cost structures. Compared to traditional meat, cultured meat (CM) production is capital intensive. This is reflected in high investment costs and high capital expenditures per kg CM produced (~30 % of costs), which are estimated. Moreover, culture meat production is likely to be rather work intensive, with significant share of labour cost (20-25%) as well as the growth medium (30%) needed for cultivation (CE Delft 2021; Sinke et al. 2023). Instead, there is only hardly information on costs structure for plant-based meat, most likely as costs may significantly differ between the various products with different proteins used. An analysis by the Good Food Institute (GFI 2023) reveals that costs are rather similar distributed across the categories channel costs and margins (e.g., retailer margins and fees, manufacturer margins), production and packaging, ingredients, sales and marketing,, general administrative expenses, R&D. For the future, potential for cost reduction is seen in various categories and price competitiveness compared of traditional meat as realistic (GFI 2023).

Based on these estimations the input structures of the four above named meat categories (beef, pork, poultry and other meat products) are modified by taking account the share of

[1] Other used names are cell-based meat, cultured meat, in vitro meat, lab-grown meat, laboratory meat.

substituted values and the alternative input structure for these shares. In other words, we keep the sector meat production in its size but consider that the above mentioned share is presented by alternative meat, which leads to different average input structure. Hence while feed and livestock cultivation and partly transport is declining, the input of (bio-)chemicals for meat cultivation, plant feedstock, capital, partly R&D costs are increasing. Although some change in capital costs are likely, those effects are not taken up in the model, as considerable high modeling adjustments for rather small overall effects would have to be made.

Table 15: Assumptions for the wedge Alternative Meat

Product group as input from	Into product group	Country	Change compared to 2021
Leguminous crops and oil seeds	Meat production (Beef, pork, poultry, other meat products)	Germany	Increase of input coefficient to 0.015 by 2050
Vegetables, roots, tubers,	Meat production (Beef, pork, poultry, other meat products)	Germany	Increase of input coefficient to 0.015 by 2050
Basic chemical, pharmaceuticals	Meat production (Beef, pork, poultry, other meat products)	Germany	Increase of input coefficient to 0.015 after 2030
Meat (Raising of Cattle, swine, poultry, animals n.e.c., production of beef, pork, poultry, other meat products)	Meat production (Beef, pork, poultry, other meat products)	Germany	Decrease to 90% by 2030, 75% by 2050
Food products (Cereal products, vegetable products, fruit products, food products and feed, sugar refining and cacao	Meat production (Beef, pork, poultry, other meat products)	Germany	Decrease to 95% by 2030, 85% by 2050
Transport (Wholesale and retail trade, road, rail, pipeline, water, air, services to transport	Meat production (Beef, pork, poultry, other meat products)	Germany	Decrease to 95% by 2030, 87,5% by 2050
Professional, scientific and technical services	Meat production (Beef, pork, poultry, other meat products)	Germany	Increase to 130%

Source: based on ISI

3.3 Organic farming

For the wedge organic farming, we assume that 100% organic farming, as a thought experiment, will be practiced in Germany by 2050. Until then, there will be a linear increase in this share.

Sources on the lower yields (expressed as lower production of the respective product groups in GLORIA) of organic farming compared to conventional farming come from the Öko-Institut and are based on data from Destatis, BMEL/BLE, UBA and KTBL. Changes in demand (e.g. due to changes in product prices) are not assumed. For production in Germany, it is assumed that the area under cultivation remains unchanged and that demand is covered by additional imports. In the case of wheat, exports are reduced to the same extent as production.

This changes the biomass flows and thus the footprint of the German bioeconomy both in the exporting countries and in Germany compared to the reference scenario. Other differences in organic farming, such as lower pesticide use or fertilizer use, including a shift from mineral to organic fertilizer and higher labour input, are not taken into account here, but would be important for a more realistic scenario.

Table 16: Assumptions for the wedge organic farming in 2050

Product group	Sector	Country	Change in production compared to Reference in 2050
Wheat	Yields	Germany	Decrease to 47% by 2050
Maize	Yields	Germany	Decrease to 45% by 2050
Cereals n.e.c.	Yields	Germany	Decrease to 76% by 2050
Leguminous crops and oil seeds	Yields	Germany	Decrease to 90% by 2050
Vegetables, roots, tubers	Yields	Germany	Decrease to 58% by 2050
Sugar beet and cane	Yields	Germany	Decrease to 50% by 2050

Source: CESR based on https://www.oekolandbau.de/handel/marktinformationen/der-biomarkt/marktberichte/ertraege-im-bio-logischen-und-konventionellen-landbau/ (accessed Aug 2024; accessible via web.archive.org)

3.4 Wedge non-food biomass for bioenergy and biomaterials

The narrative of the non-food biomass wedge for bioenergy and biomaterials follows a what-if scenario approach in order to highlight alternative pathways from the reference scenario. The aim of the wedges is to explore key levers for change by isolating parameters that could contribute to (or harm) a sustainable transition. The narratives in bioenergy sectors are split between the main demand sectors of transport and electricity/heat generation (biogas/biomethane). Again, there is also a scenario included for the chemical sector. As in the reference case, mainly cultivated agricultural biomasses are in focus. The wedge is called non-food biomass wedge since it entails the aim to reduce but not completely phaseout the overall usage of cultivated agricultural biomass (crops) across the bioenergy and biomaterials sectors. Overall the non-food biomass wedge and the reference scenario represent two contrasting future agricultural biomass demand scenarios.

The narrative for the wedge in the **transport sector** is aligned to the latest proposal of a working paper of the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, which was published at the beginning of 2023 and entails a phase out of conventional biofuels. As a result of the war in Ukraine, prices for agricultural products have risen significantly and it is seen as a necessity to increase the availability of areas for food production and therefore a reduction of cultivated biomass for energetic purposes. The aim is to reduce price pressure and the environmental impact of growing energy crops. For this purpose, two measures are described by the proposal. The first measure is the lowering of the upper quota limit for biofuels from food and feed and the second one to adapt the compensation by eligible fulfilment options (BMUV 2023). It should be noted that in the non-food biomass wedge of this narrative, the focus mainly follows the proposal mentioned above of reduced crops and land consumption. It should be stressed that a reduction in conventional biofuel consumption reduces the current overall GHG reductions in the transport sector, because conventional biofuels still play a substantial role for GHG emission reductions in transport (Umweltbundesamt 2024; Bundeszollverwaltung 2024). Furthermore, a faster phaseout of conventional biofuels than allowed by EU policy will likely further increase penalty payments towards the EU due to lacking climate protection efforts in the transport sector (Transport and Environment 2024).

Table 23 in the annex shows the assumptions for the narrative in the non-food biomass wedge. The following central assumptions are made for the transport sector in the non-food biomass wedge:

- Phasing out of conventional biofuels until 2030.
- The GHG-Quota/REDIII are the most important regulatory frameworks.
- Focus is on the used biofuels in Germany.

Overall, the future use of crops for biofuels will decline significantly in the non-food biomass narrative. Palm oil will no longer be used at all from 2024 onwards. In the long-term perspective, perennial and woody crops are required as advanced biofuels for the aviation and maritime transport sector (see Table 23). Liquid biofuels are phased out until 2030 as in the reference scenario.

Table 17: Assumptions on biofuel use in Germany in the non-food biomass wedge narrative in t of renewable raw materials

	2020	2030	2040	2050
Total conv. biofuels	15,016,466			
Perennial/woody crops (SRC) – advanced biofuel	-		1,850,000	3,700,000
Total biofuels	15,016,466		1,850,000	3,700,000
Liquid biofuels (electricity and heat)	517,239			

Source: own calculation based on BLE (2024) and BMUV (2023); assumption with regard to woody crop based advanced biofuels demand: reduction by 50 % compared to reference scenario due to stronger growth of Renewable Fuels of Non-Biogenic Origin (RFNBO's)

In the non-food biomass wedge, the use of crops for **electricity and heat generation** will decrease by 93 % by 2030 compared to the use levels of crops in 2020 (FNR 2024). After that, the quantities used will remain unchanged. Similar to the reference case, the tenure track regulatory framework is the most important one. In the non-food biomass case, assumptions are based on the evaluation of a reduction of cultivated biomass (Dotzauer et al. 2022). In this balance sheet approach, excluding technically possibilities, the production of power is decreasing from bioenergy plants. This decrease would be sufficient to reduce the amount of maize-silage used completely and would set free about 400,000 ha of land. The remaining used biomass accounts for 21 TWh of energy production and could potentially be substituted with residue and by-products along assumed mobilisation potentials. The mobilisable potentials are theoretically about 17.7 TWh, which results in a usage of 7 % of renewable raw materials in 2035 for a biogas plant portfolio of around 3.8 GW. Following these assumptions, maize as input substrate is completely abandoned and the remaining

7 % of cultivated biogenic raw materials are probably grass silage or other alternative cultivated plants used for biogas production.

For non-food biomass wedge the following central assumptions have been made for electricity and heat production:

- Reduction of biogas portfolio capacity until 2035 based on EEG 2021.
- Complete reduction of maize as input substrate because of reduction of capacity.
- Based on 2022 biogas plant portfolio.
- Following the storyline, the biogas plant portfolio should be adapted to support the energy transition to 100 % renewables in 2035.

In the non-food biomass wedge for the **chemical sector** the narrative is following a hypothetical approach. A smaller share of crop-based biomass is used compared to the reference scenario and this will continue until 2050. The main sources for renewable carbon are other sources, such as power to gas/liquid in combination with direct air capture, carbon capture and use, as well as carbon from recycling (Purr et al. 2021). The biomass streams of about 2.46 Mio. t cultivated biomass remains unchanged. Additional future biomass demand for the chemical sector will be sourced 50 % from residue and by-products as well as 50 % from primary resources from forests. This assumptions follows the case for biorefinery approaches already implemented (Verband der chemischen Industrie et al. 2023; Mantau 2023). The aim in this narratives is to limit the land use impact of crops cultivation for the chemical sector.

Table 18: Assumptions for biomass use in the non-food biomass wedge

Product group	Sector	Country	Change compared to 2020
Maize, cereals, oil seeds, sugar	Power generation (93)	Germany	Decrease by 93 % by 2030
Maize, cereals, oil seeds, sugar	Refined petro products (63)	Germany	Decrease by 100 % by 2030
Organic chemicals,	Refined petro products (63)	Germany	Decrease by 100 % by 2030
Vegetable oil	Refined petro products (63)	Germany	Decrease by 100 % by 2030
Fibre crops	Refined petro products (63)	Germany	Increase to 0.5 % of output by 2040, 1 % by 2050
Oil seeds (4)*	Shares of Indonesia, Malaysia in German imports	Germany	Decrease of 50 % in 2024
2, 4, 6, 10, 21, 51-53	Basic organic chemicals (68), Dyes, paints, glues, detergents and other chemical products (70)	Germany	Unchanged compared to 2020
Forestry and logging (21)**	Rubber products (71)	Germany	Unchanged compared to 2020

Sugar refining (51), Basic organic chemicals (68)	Clay building materials (73)	Germany	Unchanged compared to 2020
Maize (2), vegetables, roots, tubers (6)	Pulp and paper (60)	Germany	Unchanged compared to 2020
Maize (2), vegetables, roots, tubers (6)	Basic organic chemicals (68)	Germany	Unchanged compared to 2020

Source: DBFZ, own compilation. * Excluding palm oil, which is reduced by 100% until 2024. ** The GLORIA sector classification is not entirely clear in this case. Wood from forestry (except rubber) is not included here.

For the non-food biomass wedge the following central assumptions have been made for the chemical sector:

- Production capacity remains unchanged.
- Usage of 2.46 Mio. t of cultivated biomass remains unchanged.
- Regulatory framework of EU “Sustainable Carbon Cycles” is not seen as a binding regulation.
- Other carbon sources for chemical sector will be established (CCU, PtX-DAC, carbon recycling, etc.).
- Increase in lignocellulosic materials (overarching component in the VCI scenario studies).
- Integration of residue and by-products usage.

The use of cultivated biomass as input material in the chemical industry remains unchanged compared to 2020 in the non-food biomass wedge, while it will increase especially after 2030 in the reference. Table 18 concludes all the before mentioned assumptions for biomass use in this non-food biomass wedge according to the product and sector groups within the GLORIA modelling.

3.5 Water stress

Based on AQUA.STAT, the following countries were identified as having high water stress in 2020: United Arab Emirates, Kuwait, Saudi Arabia, Qatar, Bahrain, Oman, Egypt, Israel, Malta, Uzbekistan, Singapore, Syria, Lebanon, Tajikistan, Iraq, Iran, Sudan, Pakistan, Algeria, Turkmenistan, Tunisia, Jordan, Libya. These are mainly countries from the middle East, Northern Africa and Central Asia.

This wedge assumes that no more food will be imported to Germany from these countries in the future (product groups 1 to 20 and 41 to 56 in the GLORIA classification). Instead, production in Germany and the other importing countries is increased for every product group by the same (product group specific) percentage, so that the unchanged demand in Germany is met.

Table 19: Assumptions for import flows in Wedge Water stress

Product groups	Countries	Flow type	Change compared to 2021
All food and forestry (1-21, 41-56)	All with water stress	Imports	Decrease to 0
As above	All other countries	Imports	Uniform increase
As above	Germany	Production	Uniform increase as above

Source: CESR, own compilation

3.6 Central results: Bioeconomy Wedges

In the modelling, the material input according to the 120 sectors and 164 countries and regions is linked to the respective production in the MRIO model via material intensities. A decline in biotic material FP in Germany therefore means that the structures will shift towards less material-intensive sectors while the economic dynamics in the countries in terms of GDP remain unchanged by definition.

Of the various wedges, a dietary change in Germany towards the DGE recommendations by 2050 with a lower consumption of meat and dairy products has a particularly significant effect on the biotic material footprint. It is almost 11% lower in 2050 than in the reference. As the FP already decreases already in the reference, it could be 21.5 % lower in 2050 in the Wedge Diets DGE compared to 2021.

The impact of the other wedges is limited for some of the German FPs. The stop of imports from countries with water shortages (water stress) leads to a decrease in the biotic material FP of just over 1%. Obviously, the material intensity of food production in the countries with water stress is higher than in Germany and the other supplier countries to which German demand for food is assumed to be shifted. Reduced imports from these countries could have much higher effects for water stressed areas, of course.

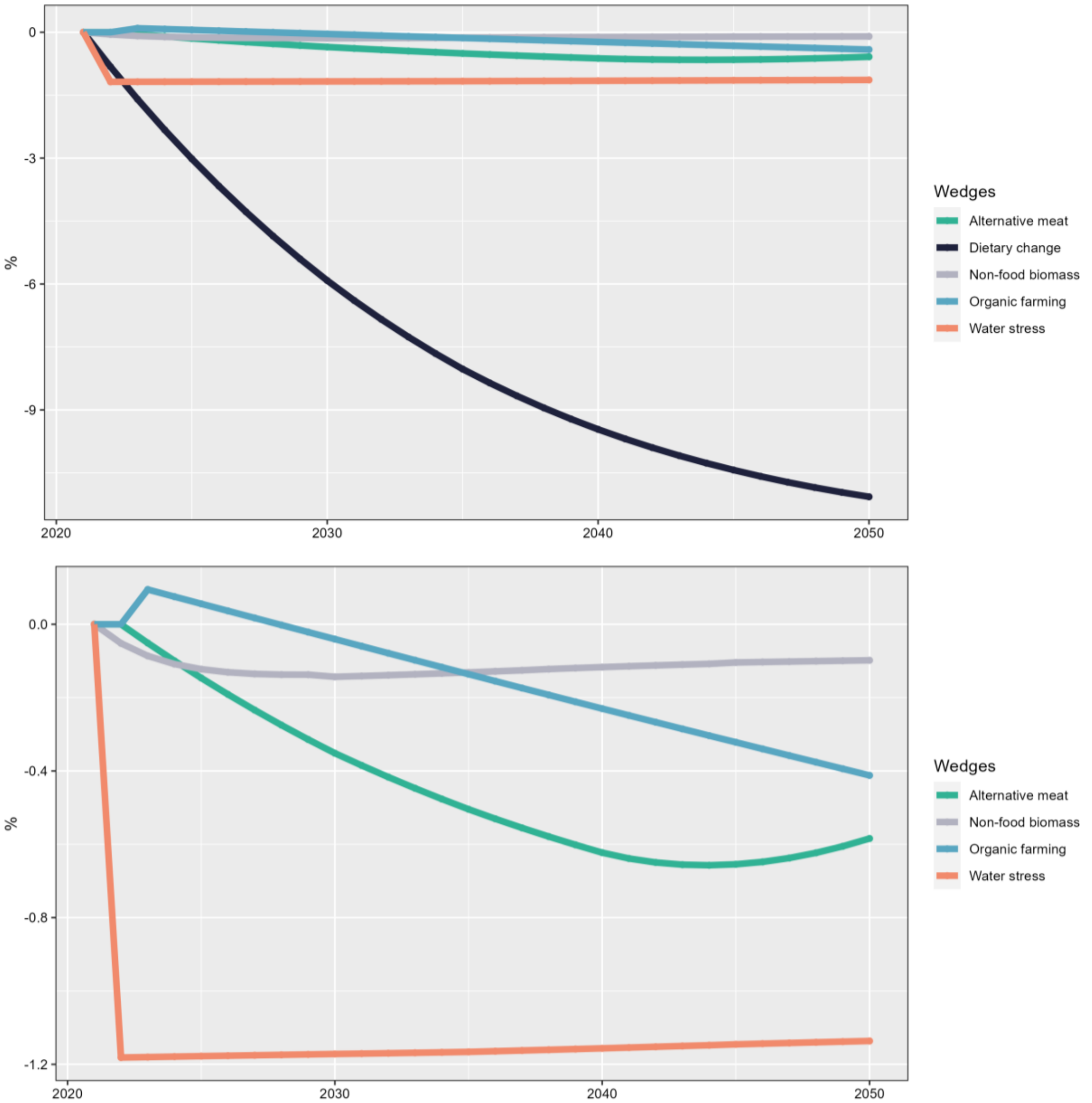
A reduced used of cultivated biomass for bioenergy and biomaterials (Wedge non-food biomass) has a very small influence on the Material FP. This is also due to the already reduced use of biofuels in the reference, which reflects EU regulation. At the same time, the material use of biomass in the wedge increases over time, which per se has an increasing effect on the material FP.

The wedge on alternative meat focuses primarily on replacing meat with plant-based and chemical substances. Due to its assumptions, it is much smaller in scale than a significant change to a plant-based diet. Biotic material inputs and related GHG emissions could be slightly lower than in the reference.

In addition to the above-mentioned wedges, a reduction of (food) waste across all stages of production, transportation and consumption could lead to lower demand for food and biomass products, which should significantly reduce the biotic material FP.

A combination of different wedges is possible, whereby the effects should essentially add up. Only the combination of dietary change and alternative meat could be somewhat more complex in terms of the assumptions because they partly overlap. As the effects of the dietary wedge currently dominates all other wedges, a combination has not been implemented.

Figure 7: Deviation from the reference (%): Biotic material footprint of domestic consumption (RMC)

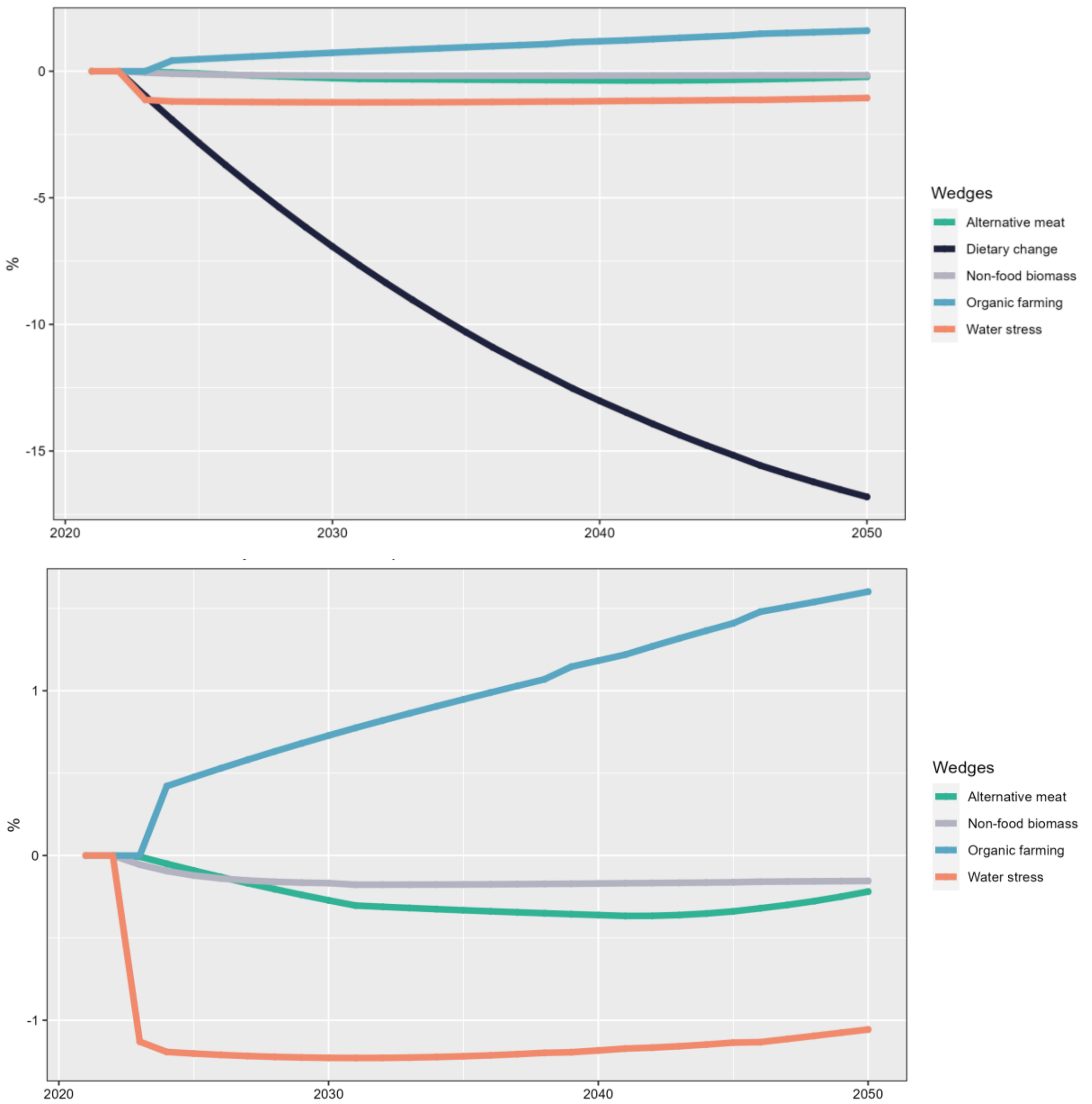


Top: Depiction of all wedges.
Bottom: Close-up view of the wedges alternative meat, non-food biomass, organic farming and water stress.

Source: GWS, own calculation based on GLORIA.

The effects on the GHG FP of the German bioeconomy tend to go in the same direction as for the biotic material FP. However, it should also be noted that GHG emissions, particularly in Europe, will fall sharply in the long term due to the assumed achievement of political targets. This will both massive gains in energy efficiency as well as significant reductions in energy consumption. In this case, additional effects of the wedges will remain limited. By far the greatest effect is that of the Wedge Diet DGE, which leads to a reduction in the GHG FP of the German bioeconomy of around 15 % by 2050. The increase in climate FP in the organic farming wedge can be explained by the simple assumptions. Expected decreases, for example due to the abandonment of mineral fertilizers, are not accounted for. Assumptions also contribute to the visible increase at the beginning of the alternative meat wedge, which may need to be adjusted.

Figure 8: Deviation from the reference (%): GHG BE footprint of domestic consumption



Top: Depiction of all wedges.
Bottom: Close-up view of the wedges alternative meat, non-food biomass, organic farming and water stress.

Source: GWS, own calculation based on GLORIA.

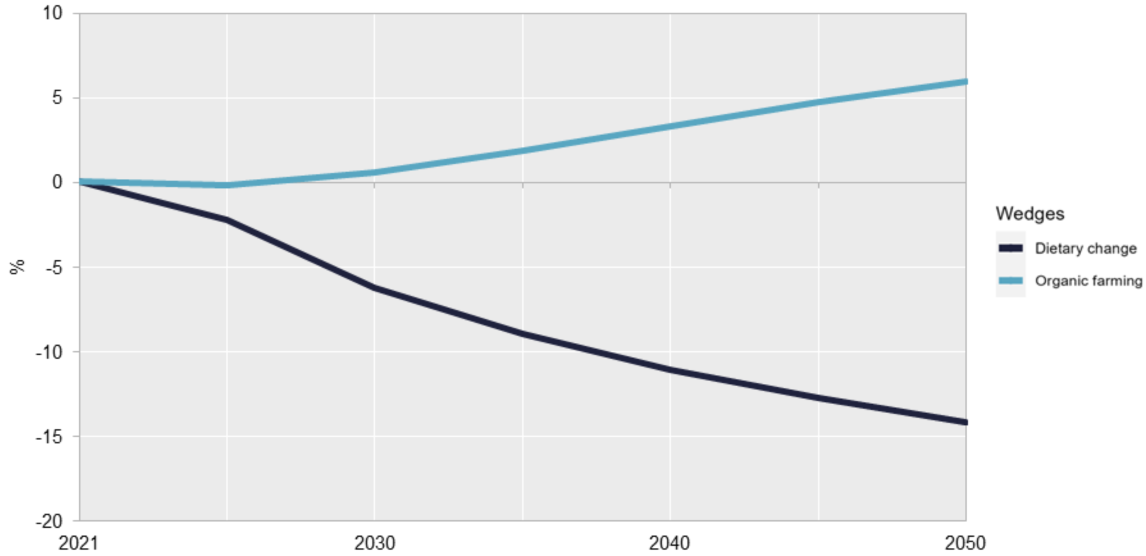
The effects on the land FP of the German bioeconomy for the two calculated wedges are in the same direction as for the GHG FP. The land FP is calculated using the spatial land-change model LandSHIFT (Schüngel et al., 2022) on the basis of the GLORIA data.

In the “what-if” thought experiment of organic agriculture, 5.9 % more land is needed by 2050 compared to the Reference. The FP is very theoretical, and assumes 100% organic farming only in Germany, leading to lower production in Germany and thus increasing land requirements in foreign countries. It should be assumed that organic farming will also increase in other regions and that Germany will also increasingly import organically grown crops in the future. A further increase in land consumption would therefore be likely.

The diets DGE wedge also has a major effect on land FP, leading to a reduction in German bioeconomy Land FP of around 14 % by 2050 compared to the Reference. This is mainly due to the drastic reduction of grassland area used for the production of meat consumed in Germany.

The assumptions show that organic farming increases the Land FP. A shift towards sustainable agriculture should be pursued with regard to positive benefits for the environment and climate.

Figure 9: Deviation from the reference (%): Land footprint



Source: CESR

4 Conclusions and outlook

In the Bioeconomy Monitoring Report 2024 (Beck-O'Brien et al. 2024) scenarios are developed and described to extrapolate the various footprints of the German bioeconomy into the future. Footprints are important indicators of the bioeconomy, that quantify also the international effects in important sustainability dimensions. In addition to a reference scenario, different wedges were developed, describing the effects of alternative future developments on the footprints. This discussion paper documents various assumptions behind these scenarios. The main conclusions for the footprints are presented in the monitoring report.

When developing the reference scenario, it becomes clear that many assumptions have to be made, which should be based on other reliable sources as far as possible. Then the results can be compared with other estimates and evaluated. The design of the transformation to climate neutrality is of great importance for the bioeconomy. Developments in the use of biomass, which are often influenced by legislation, also play a central role.

The results of the wedges show that a change in diets can significantly influence footprints. In the case of other wedges, the effects may not be as great because the cause-and-effect relationships are complex and not yet been sufficiently mapped. It also shows that individual wedges can change individual footprints much more than others and that the effects on the footprints can be complementary, but trade-offs between footprints are also possible.

An important addition to the monitoring of the current development of the bioeconomy is the view into the future. This requires scenarios that describe possible futures and can show options and needs for action. The wedge approach in section 3 shows the effects of corresponding simple what-if scenarios on the footprint. In the future, these scenarios can be made more realistic in order to make the opportunities of the future bioeconomy and the scope for political action more tangible. Corresponding highly differentiated scenarios provide a framework for orientation and action for politics and other stakeholders, for example in climate protection as part of the annual projection reports. There is a need for research in order to better quantify the contribution of the bioeconomy to sustainable development in the future.

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Appendix

Table 20: Sectors in GLORIA

Nr	Sector
1	Growing wheat
2	Growing maize
3	Growing cereals n.e.c
4	Growing leguminous crops and oil seeds
5	Growing rice
6	Growing vegetables, roots, tubers
7	Growing sugar beet and cane
8	Growing tobacco
9	Growing fibre crops
10	Growing crops n.e.c.
11	Growing grapes
12	Growing fruits and nuts
13	Growing beverage crops (coffee, tea etc)
14	Growing spices, aromatic, drug and pharmaceutical crops
15	Seeds and plant propagation
16	Raising of cattle
17	Raising of sheep
18	Raising of swine/pigs
19	Raising of poultry
20	Raising of animals n.e.c.; services to agriculture
21	Forestry and logging
22	Fishing
23	Crustaceans and molluscs
24	Hard coal
25	Lignite and peat
26	Petroleum extraction
27	Gas extraction
28	Iron ores
29	Uranium ores
30	Aluminium ore
31	Copper ores
32	Gold ores
33	Lead/zinc/silver ores
34	Nickel ores
35	Tin ores
36	Other non-ferrous ores
37	Quarrying of stone, sand and clay
38	Chemical and fertilizer minerals
39	Extraction of salt
40	Mining and quarrying n.e.c.; services to mining
41	Beef meat
42	Sheep meat
43	Pork
44	Poultry meat
45	Other meat products
46	Fish products
47	Cereal products
48	Vegetable products
49	Fruit products
50	Food products and feeds n.e.c.
51	Sugar refining; cocoa, chocolate and confectionery
52	Animal oils and fats
53	Vegetable oils and fats

Nr	Sector
54	Dairy products
55	Alcoholic and other beverages
56	Tobacco products
57	Textiles and clothing
58	Leather and footwear
59	Sawmill products
60	Pulp and paper
61	Printing
62	Coke oven products
63	Refined petroleum products
64	Nitrogenous fertilizers
65	Non-nitrogenous and mixed fertilizers
66	Basic petrochemical products
67	Basic inorganic chemicals
68	Basic organic chemicals
69	Pharmaceuticals and medicinal products
70	Dyes, paints, glues, detergents and other chemical products
71	Rubber products
72	Plastic products
73	Clay building materials
74	Other ceramics n.e.c.
75	Cement, lime and plaster products
76	Other non-metallic mineral products n.e.c.
77	Basic iron and steel
78	Basic aluminium
79	Basic Copper
80	Basic Gold
81	Basic lead/zinc/silver
82	Basic nickel

Nr	Sector
83	Basic tin
84	Basic non-ferrous metals n.e.c.
85	Fabricated metal products
86	Machinery and equipment
87	Motor vehicles, trailers and semi-trailers
88	Other transport equipment
89	Repair and installation of machinery and equipment
90	Computers; electronic products; optical and precision instruments
91	Electrical equipment
92	Furniture and other manufacturing n.e.c
93	Electric power generation, transmission and distribution
94	Distribution of gaseous fuels through mains
95	Water collection, treatment and supply; sewerage
96	Waste collection, treatment, and disposal
97	Materials recovery
98	Building construction
99	Civil engineering construction
100	Wholesale and retail trade; repair of motor vehicles and motorcycles
101	Road transport
102	Rail transport
103	Transport via pipeline
104	Water transport
105	Air transport
106	Services to transport
107	Postal and courier services
108	Hospitality
109	Publishing

Nr	Sector
110	Telecommunications
111	Information services
112	Finance and insurance
113	Property and real estate
114	Professional, scientific and technical services
115	Administrative services
116	Government; social security; defence; public order
117	Education
118	Human health and social work activities
119	Arts, entertainment and recreation
120	Other services

Lenzen et al. (2022).

Table 21: Countries/Regions in GLORIA

Nr	Sector
1	Rest of Americas
2	Rest of Europe
3	Rest of Africa
4	Rest of Asia-Pacific
5	Afghanistan
6	Angola
7	Albania
8	United Arab Emirates
9	Argentina
10	Armenia
11	Australia
12	Austria
13	Azerbaijan
14	Burundi
15	Belgium
16	Benin
17	Burkina Faso
18	Bangladesh
19	Bulgaria
20	Bahrain
21	Bahamas
22	Bosnia and Herzegovina
23	Belarus
24	Belize
25	Bolivia
26	Brazil
27	Brunei Darussalam
28	Bhutan
29	Botswana
30	Central African Republic
31	Canada
32	Switzerland
33	Chile
34	China
35	Cote d'Ivoire
36	Cameroon
37	DR Congo
38	Rep Congo
39	Colombia
40	Costa Rica
41	Cuba
42	Cyprus

Nr	Sector
43	Czech Republic
44	Germany
45	Djibouti
46	DR Yemen (Aden)
47	Denmark
48	Dominican Republic
49	Algeria
50	Ecuador
51	Egypt
52	Eritrea
53	Spain
54	Estonia
55	DR Ethiopia
56	Finland
57	France
58	Gabon
59	United Kingdom
60	Georgia
61	Ghana
62	Guinea
63	Gambia
64	Equatorial Guinea
65	Greece
66	Guatemala
67	Honduras
68	Hong Kong
69	Croatia
70	Haiti
71	Hungary
72	Indonesia
73	India
74	Ireland

Nr	Sector
75	Iran
76	Iraq
77	Iceland
78	Israel
79	Italy
80	Jamaica
81	Jordan
82	Japan
83	Kazakhstan
84	Kenya
85	Kyrgyzstan
86	Cambodia
87	South Korea
88	Kuwait
89	Laos
90	Lebanon
91	Liberia
92	Libya
93	Sri Lanka
94	Lithuania
95	Luxembourg
96	Latvia
97	Morocco
98	Moldova
99	Madagascar
100	Mexico
101	Macedonia
102	Mali
103	Malta
104	Myanmar
105	Mongolia
106	Mozambique

Nr	Sector
107	Mauritania
108	Malawi
109	Malaysia
110	Namibia
111	Niger
112	Nigeria
113	Nicaragua
114	Netherlands
115	Norway
116	Nepal
117	New Zealand
118	Oman
119	Pakistan
120	Palestine
121	Panama
122	Peru
123	Philippines
124	Papua New Guinea
125	Poland
126	North Korea
127	Portugal
128	Paraguay
129	Qatar
130	Romania
131	Russian Federation
132	Rwanda
133	Saudi Arabia
134	South Sudan
135	Senegal

Nr	Sector
136	Singapore
137	Sierra Leone
138	El Salvador
139	Somalia
140	Serbia
141	Sudan/North Sudan
142	Slovakia
143	Slovenia
144	Sweden
145	Syria
146	Chad
147	Togo
148	Thailand
149	Tajikistan
150	Turkmenistan
151	Tunisia
152	Turkey
153	Tanzania
154	Uganda
155	Ukraine
156	Uruguay
157	United States of America
158	Uzbekistan
159	Venezuela
160	Viet Nam
161	Yemen Arab Republic
162	South Africa
163	Zambia
164	Zimbabwe

Source: Lenzen et al. (2022).

Table 22: Food consumption in kg per capita in Germany

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Trend	2030
Cereal products (flour value)	93.4	98.3	96.8	82.4	83.8	83.9	85.5	85.8	85.8	84.4	84.7	84.6	no trend	84.6
Rice	5.0	5.4	5.3	5.5	5.4	5.3	5.2	5.8	5.4	6.3	6.8	6.6	+0,11 kg/year	7.6
Potatoes	64.5	57.9	62.0	59.8	58.1	58.0	57.5	57.9	60.4	55.4	57.2	59.6	no trend	59.6
Vegetables, fruit (market cultivation)	224.1	213.6	212.0	209.2	207.4	208.3	206.8	207.2	214.4	212.4	215.2	222.7	no trend	222.7
Sugar including beet juice (white sugar)	34.6	34.3	35.6	37.6	33.9	35.4	33.8	33.7	34.8	34.6	33.7	32.5	no trend	32.5
Meat and meat prod-ucts (slaughter weight)	91.2	91.8	89.1	89.0	89.3	89.4	88.7	88.1	90.1	85.8	84.2	82.1	-0,38 kg/year	78.6
Fish and fish products (catch weight)	16.0	15.7	14.6	13.5	14.4	13.5	14.4	14.1	14.5	14.3	14.8	12.7	no trend	12.7
Milk and milk products	115.4	117.8	114.9	114.4	116.2	116.4	122.1	120.6	120.1	118.0	118.4	115.9	no trend	115.9

Source: BMEL (2022)

Table 23: Assumptions for the reductions (%) of final energy demand in the non-food biomass wedge narrative

Unit/Year	2020*	2021**	2022	2023	2024	2025	2026	2027	2028	2029	2030***	2040***	2050***
End energy demand transport SYMOBIO in PJ	2,283	2,253	2,219	2,184	2,150	2,116	2,081	2,047	2,013	1,978	1,944	1,337	1,062
cultivated renewable raw materials used for biofuel production (waste and residues excluded) in PJ	122	99	98	96	49	44	40	39	24	24	0	0	0
% of biofuels in relation to final end energy demand are generated by cultivated renewable raw materials	5.2	4.4	4.4	4.4	2.3	2.1	1.9	1.9	1.2	1.2	0.0	0.0	0.0
Reduction in % biofuel production from cultivated biomass used for biofuel production (reference 2020)		-19 %	-20 %	-21 %	-59 %	-64 %	-68 %	-68 %	-80 %	-81 %	-100 %	-100 %	-100 %

* (Bundesanstalt für Landwirtschaft und Ernährung 2022b; Schröder and Naumann 2022); ** (Bundesministerium für Digitales und Verkehr/Federal Ministry for digital and transport 2022; Bundesanstalt für Landwirtschaft und Ernährung 2022b); ***own calculation of final energy demand: Value Dena- KN100 + ((Value BMWK LFS TN-Strom – Value Dena- KN100)/2) see reference case for explanation